ground water

Historical Note/ David Deming, History Editor

The Canadian School of Hydrogeology: History and Legacy

by József Tóth[1]

In the early 1960s, some young earth scientists in the Canadian Prairies discovered a previously unrecognized aspect of subsurface hydrology: topography-induced ground water flow systems. With seminal contributions by colleagues in Canada and abroad, the concept evolved into a new hydrogeological paradigm, spawned a veritable school of scientific thought, and, by the 1980s, had changed the scope of hydrogeology. Rapid developments of such far-reaching consequences are infrequent in the histories of scientific disciplines. The purpose of this brief retrospect is to record the chief factors and circumstances that produced the paradigm shift and the modern scope of the discipline.

Background to the School's Development

Institutional programs of ground water exploration and research began on the Canadian Prairies, which occupy the southern portions of Alberta, Saskatchewan, and Manitoba, in the late 1950s. Prior to 1950, water for farms, towns, and the few small local industries was obtained from natural springs and dugouts initially, and later from shallow dug, bored, or drilled wells constructed by farmers or by self-educated drillers, often assisted by the divining rod. In 1957, Canada's largest group responsible for the exploration and development of the entire country's ground water resources, the Ground Water Section of the Geological Survey of Canada (GSC), had a staff of "five men, only three of whom are engaged in groundwater studies in the field" (Pollitt 1957, p. 87). The widespread programs of ground water exploration and concomitant mission-oriented research were prompted by the sudden demand for central water-supply systems in rural municipalities after World War II. In response, the Research Council of Alberta (RCA) established its Ground Water Division in 1955. The rationale for the institutional approach was articulated in the first formal statement on the question by an American consultant (J.W. Foster) and R.N. Farvolden, the first Head of RCAs newly established Ground Water Division: "...There are water supply problems in Alberta today ... The severity of the problems ... will depend on the use of foresighted planning and research into the geologic and hydrologic conditions of the province" (Foster and Farvolden 1958, p. 4–5). Although Farvolden left the RCA in 1960 to pursue the Ph.D. at the University of Illinois, the seeds were sown. By 1968, the Division employed 10 professionals and 16 technical and administrative staff. Also, its objectives and tasks had expanded "To solve, or to provide information for the solution of current problems in groundwater-related fields (hydrogeology in the broad sense), and to evaluate pertinent aspects of the groundwater regime on a province-wide basis in advance of human development" (J. Tóth, RCA Division Head, 1968).

By 1968, the geologic agency of regional ground water flow was recognized from numerous flow system studies conducted in every province of Western Canada and beyond. Accordingly, the mechanisms and effects of interaction between moving ground water and its environment were studied, and the resulting understanding applied to problems in pedology, botany, soil and rock mechanics, petroleum geology, mineral exploration, and land-use planning, in addition to ground water exploration and development.

But the sudden demand for professional-level ground water investigations could not be met with ready-made hydrogeologists from Canada or abroad. The members of the first group, some 10 or 15 who started in the Prairies before 1965, were geologists, geophysicists, one paleontologist, one hydrologist, and the odd engineer, from Canadian, European, or American universities; they all had to learn ground water on the job. Paradoxically, ignorance of hydrogeology turned out to be a blessing in disguise: it led to questions in a hydrogeological terra incognita, where we were challenged to find our own solutions tested by real life. The situation fostered original thoughts and discoveries.

We also had a genuine desire to understand ground water, and an unbridled enthusiasm as evident in a letter

[1]Professor Emeritus, Hydrogeology, Department of Earth and Atmospheric Sciences, University of Alberta, Edmonton, AB, T6G 2E3 Canada; (780) 492-5740; fax: (780) 492-2030; joe.toth@ualberta.ca

from Meyboom, written shortly after leaving the RCA to join the GSC in 1961. Referring to our group, and our interest in ground water flow systems, as the "Prairie school of hydrogeology" he wrote, "We are the vanguard of a crushing army against the American hydrology, against the 'water-well approach' as I am going to call it from now on" (Meyboom 1962d).

Some history is captured in an ad hoc interview with P. Meyboom by R.E. Jackson (1977), concerning "... the historical development of the conceptual model of regional ground-water flow on the Prairies in the 1950s and 1960s" (P. Meyboom, personal communication, 2002). In an attempt to relate Hubbert's theory of ground water motion (Hubbert 1940) to observable field phenomena, Meyboom and Tóth went "... on a field trip in June 1961 camping out on the way 'as real geologists did' [Figure 1] ... They were very successful. Tóth told Meyboom in Dutch, 'I have had a mental epiphany'... Following the June 1961 field trip, Tóth and Meyboom went their separate ways as Meyboom left the RCA and joined the GSC ... They did not meet again until the Calgary meeting in November 1962. Meyboom and Tóth presented their individual impressions of what they had seen at this meeting and, rather than realize the joint strength of their combined work, there was some animosity between them due to both feeling that each had the key for the paradigm of regional ground-water flow ... Meyboom concluded [the interview] by noting that we in Canada now have a 'national school' of hydrogeology based on regional ground-water flow studies, a point that was echoed by Domenico in his first book (Domenico 1972, p. 254)." The notion of a "national school" in Canada was bolstered also by field trips and conferences that we organized during 1964 to 1978 on regional ground water flow.

The School-Forming Concept: Regional Ground Water Flow

One way to acquire the hydrological knowledge needed to perform our daily duties (estimating well yields or regional resources) was, we thought, to understand the relations between field manifestations and availability of ground water. Meyboom, a paleontologist-geologist, focused on "ground water outcrops," i.e., surficial indications, as possible clues to ground water conditions. On the other hand, based on my background in geophysics and on Hubbert's (1940) concept of the fluid potential, I wanted to know the trajectory of a drop of ground water traveling from the water table to the place it resurfaces. I, thus, compared the hydrologic implications of Hubbert's (1940) figure 45 with the flows of my area's creeks. Figure 45 showed all infiltrated water to discharge in the valley's thalweg as if it were a drainage ditch. Yet, most creeks in my area were dry at many places and frozen to the bottom in the winter. The creeks were spaced at 10 to 15 km in parallel valleys of 150- to 200-m relief, cut into sandstones and siltstones, and with water tables no deeper than 3 m even on the divides. Where does all the infiltrated water go if not to the thalweg, driven by the steep gradients through permeable rock, providing sufficient supplies to farms and towns, I wondered? Discharge vs. recharge appeared completely out of balance. Then one day, I realized that convergence of the flow lines in Hubbert's picture was an imposed condition, an a priori postulate, not a result! I decided then to determine where the water wants to go by itself and did what I believe was the first study devoted explicitly to the quantitative analysis of regional ground water flow in a Prairie environment (Tóth 1962a): an analytical solution to the Laplace equation in terms of Hubbert's hydraulic head, $h = z + p/\rho g$, for a flow domain with linearly sloping water table. Soon I realized the basic difference in the messages of figure 45 and my two-dimensional cross sections: instead of ground water from the whole basin resurfacing along a single line of discharge in the thalweg, the entire lower half of the basin was an area of discharge. The work drew a quick and positive response from the international community, as well as a scathing discussion from Davis (1963). I rebutted his criticism (Tóth 1963a) and was corroborated later by Freeze and Witherspoon (1967).

In order to better approximate reality, I replaced the basin's linear water table by a sinusoidal one (Tóth 1962b) and presented the results at a symposium in Calgary, in 1962, where also Meyboom (1962a) presented his paper on ground water flow in the "Prairie Profile." His study was based on well water levels and ground water outcrops, which he defined as "... any area where ground-water emerges at the surface" (op. cit. p. 11). At the meeting, the two models were seen as vying for recognition as the paradigm of ground water hydraulics for the Prairies (Figure 2). The impression was reinforced by our written discussions (Meyboom 1962b, 1962c; Tóth 1962c, 1962d). As I stated then and still hold, our disagreement on some specific details notwithstanding, the combined picture presented by the two models "... gives a good description of the unconfined region of groundwater flow in the western Canadian Prairies" (Tóth 1962d, p. 26). However, the mathematical language of my model made it amenable for validation and further development, just in time for the powerful new technique of numerical modeling. The

Figure 1. P. Meyboom (left) and J. Tóth getting ready to search for clues to regional ground water flow on the Prairies, Tolman ferry campground on the Red Deer River, southern Alberta, June 1961.

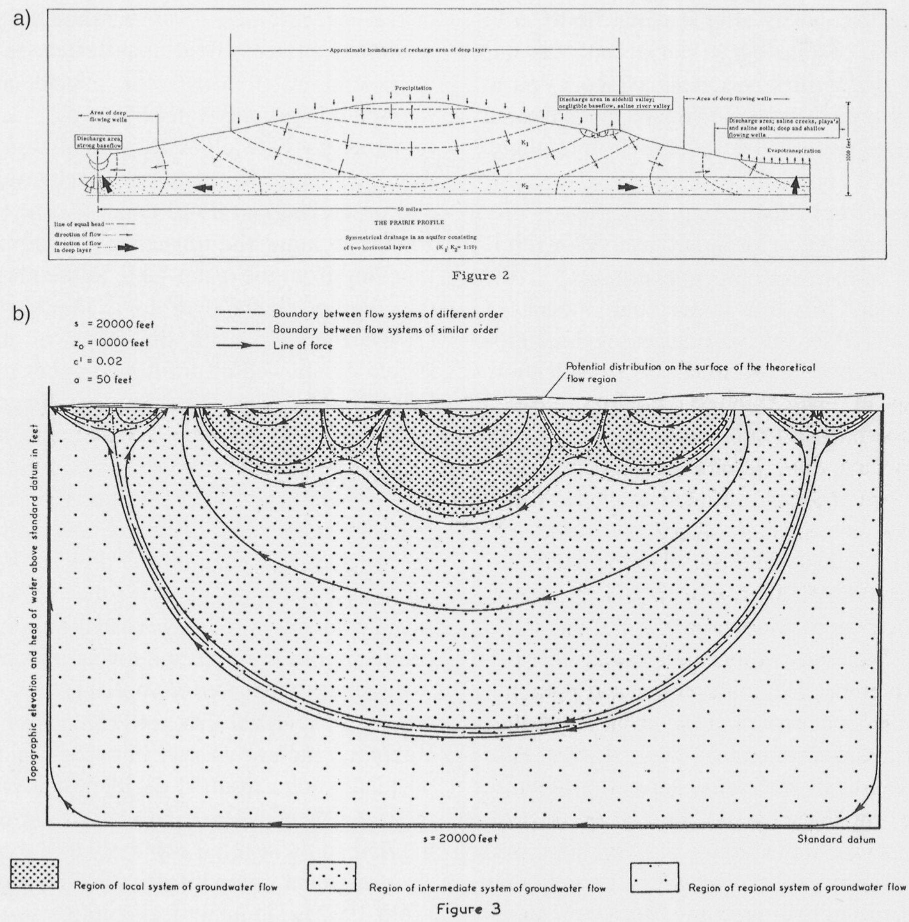

Figure 2. The foundation of the Canadian school of hydrogeology, two basic flow patterns: (a) The Prairie Profile (Meyboom 1962a, figure 2) and (b) composite drainage basin (Tóth 1962b, figure 3).

regional flow system concept gained acceptance soon due mainly to the publication of Freeze's Ph.D. work (Freeze and Witherspoon 1966, 1967) and partly to the results of numerous modeling and field studies (e.g., Domenico and Palciauskas 1973; Freeze 1967, 1969; Fritz 1968; Lawson 1968; Meyboom et al. 1966; Mifflin 1968; Rozkowski 1967; Tóth 1966; Williams 1970).

An unexpected result of the early flow system studies was the recognition of systematic associations of various natural phenomena and processes with identifiable segments of flow systems. That recognition motivated studies in Canada and abroad dedicated to specific hydrologic processes and effects. Following is an illustrative sampling of such studies: soil salinization and botany (Macumber 1991); geothermics (Bodmer and Rybach 1985; Smith and Chapman 1983); ground water chemistry (Schwartz and Domenico 1973); morphology (De Vries 1977); hydrology (Ortega and Farvolden 1989; Winter 1978); genesis of uranium deposits and metallic minerals (Galloway 1978; Garven and Freeze 1984); migration and accumulation of petroleum (Sanford 1995; Tóth 1988; Verwij 2003); and general: principles, applications, overviews (Deming 2002; Domenico 1972; Freeze and Cherry 1979; Tóth 1999). By the 1980s, it was firmly established that flowing ground water is a general geologic agent.

The Legacy of the Canadian School of Hydrogeology

Meyboom's use of the term "national school" of hydrogeology (Jackson's notes, p. 3) is valid by dictionary definition of a school: "A group of persons, especially intellectuals or artists, whose thought, work, or style demonstrates some common influence or unifying belief" (Morris 1973). The common focus in our work was noted by Domenico (1972, p. 254), who pointed out that the two basic approaches to regional ground water flow studies are "field and theoretical" and then noted that "… These ideas have … been rediscovered and advanced by a group of Canadian hydrologists."

The two principal commonalities influencing our collective thought and work were topography-induced regional ground water flow systems and their geologic agency. These two notions have profoundly altered the nature and scope of hydrogeology from a discipline of exploration and development of ground water resources into a basic earth science. The ground water flow system has become a generally accepted paradigm. It is discussed routinely in textbooks and monographs (e.g., Engelen and Kloosterman 1996; Schwartz and Zhang 2003; Shibasaki 1995; Zijl and Nawalany 1993). All these start with regional ground water flow from the Canadian work of the 1960s. Also intriguing is the occasional use of some stylized version of the composite ground water flow pattern as a logo on book covers (e.g., Freeze and Cherry 1979; Pollock 1989; Shibasaki 1995). The references listed in Tóth (1999) illustrate the scope-widening role of the "general geologic agency" notion of flowing ground water.

A third, less obvious but equally important, legacy of the Canadian school is its effect on education. Members of the group introduced hydrogeology courses and programs at universities in Canada and the United States. J.A. Cherry was the first to teach hydrogeology at the University of Manitoba in 1967, with "... a major focus on groundwater flow-systems (Tóth, Meyboom) ... and interactions with the natural environment such as groundwater hydrochemistry and soil salinity" (Cherry 2005). R.N. Farvolden, who succeeded G.B. Maxey at the University of Illinois in 1964, not only introduced the Canadian ideas but influenced Maxey to test those ideas at the University of Nevada—Reno (Mifflin 1968). Farvolden continued to spread the word in Canada at the universities of Western Ontario and Waterloo, where he established the most senior ground water program in the country. Although R.A. Freeze was not the first to teach ground water hydrology at the University of British Columbia he was "... the first faculty member hired to set up a groundwater program at UBC ..." (Freeze 2005). He also "... revamped the groundwater course (along the lines that ultimately appeared in Freeze and Cherry) [1979] ... with emphasis not just on aquifers and pump tests, but also on flow systems, hydrological interactions, ore genesis, land subsidence, etc." I introduced hydrogeology at the University of Alberta in 1965 and the University of Calgary in 1978.

The combination of a genuine and acute demand for increased supplies of ground water on the Canadian Prairies and the minds, mentality, and energy of a dozen or so hydrogeologically uninitiated young professionals working independently but synergistically produced a uniquely creative period of lasting scientific results during the 1960s to 1970s that helped change a single-issue discipline of ground water resources development into the multifaceted earth science that we know today as modern hydrogeology.

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